RF Requirements for Bunching in the Recycler for Injection Into the g-2 Ring

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August 25, 2008

Abstract

A proposal to site the BNL/BU g-2 Ring[1] at Fermilab is being considered. The possibility of implementing a practical scheme quickly and inexpensively using existing Fermilab facililities soon to be available for adaptive reuse is attractive both for fundamental physics reasons and for program continuity. This note presents a conceptual solution to one of the major technical challenges raised by the proposal, *viz.*, the bunching of Booster batches in the Recycler to a few sub-μs bunches suitable for producing muon beam of required time structure. The result given is by no means the last word on this subject, but it has potential for accommodating changes that may be more economical or more tolerant of the operational vagaries of the Booster. Such development of the concept is beginning. Costing using these initial results should be meaningful, but less idealized results should be available soon.

1 Introduction

M. Popovic, C. M. Ankenbrandt, R.P. Johnson, and several others[2] have described the basis for the work here reported. We have developed a scheme which uses existing Fermilab facillities and hardware to accomplish the bunching. For a technical demonstration of feasibility (or, if you will, proof of principle) we invoke additions of like kind to the existing hardware to provide currently unavailable rf voltage. Also, we have taken the acceptable upper limit on the length of the injected pulse to be ~ 100 ns in place of the 30 ns in the Popovic *et al*. description, on the (possibly unjustified) assumption that the existing injection kicker can be improved sufficiently to make more of the 147 ns beam circulation period useful. The potential refinements discussed in Sec. 4 include strategies for reducing bunch length or reducing rf voltage requirements. The quantities listed in Table 1 are supposed to reflect the current values of parameters relevant to the bunching process.

2 Qualitative Description of the Bunching Scheme

The bunching scheme is to use a four period sawtooth wave form across the Booster batch produced by the broadband rf system to break the batch into four segments and rotate them sufficiently that they can be rotated cleanly in a linearized bucket provided by the resonant rf. Each of the four resulting bunches is ~ 100 ns long. The first bunch is extracted immediately and the latter three are extracted sequentially at half periods of the synchrotron oscillation. The beam loading of the resonant cavities is considerable, and we have not considered the details of a good solution. It is plausible to expect that a feedforward system can be developed without serious difficulty. A combination of feedback with feed foreward is potentially better yet, but feedforeward will be required with or without feedback.

Table 1: Current parameters available for the bunching process

Quanty	Value	Units
2.5 MHz (h=28) peak voltage	75.	kV
5.0 MHz (h=56) peak voltage	15.	kV
broadband rf peak rf voltage	2.	kV
Recycler equilibrium radius	528.5	m
Recycler transition γ	19.97	
Booster ε_ℓ per 53 MHz bunch	0.12	eVs

Table 2: Parameter choices for modeling of the bunching process

Quanty	Value	Units
2.5 MHz (h=28) peak voltage	80.	kV
5.0 MHz (h=56) peak voltage	16.	kV
broadband rf peak rf voltage	4.0	kV
Booster ε_ℓ per 53 MHz bunch	0.07	eVs

The broadband rf is like that already installed in the Recycler except for providing 4 kV instead of 2 kV. The 2.5 and 5.0 MHz rf needs to be moved from the MI to the Recycler, and perhaps the 2.5 MHz voltage limit needs to be increased to 80 kV and the 5.0 MHz bumped up to 16 kV.

3 Feasibility

The bunching process has been modeled with ESME[3] with multiple trials to determine satisfactory beam quality without trying to simultaneously observe fixed economic or operational constraints. The practicability of working toward some desirable limitations is mooted in Sec. 4. The final values of the specific parameters varied for the several trials appear in Table 2.

Fig. 1 shows the rms momentum spread of the Recycler *vs*. time. The four maxima are at the times the bunch widths are minimum and are suitable for extraction. The $\Delta p/p$ is about 0.8 % full width. Therefore, if the effective ε_ℓ in the Booster is much larger than the 0.07 eVs assumed, the momentum aperture of the Recycler becomes a critical concern. The bunch time profiles appear in Figs. 2 and 3.

4 Potential Refinements

The possibilities of adapting the scheme to greater ε_ℓ or lower rf peak voltage appear to have the higher immediate priority. Also, reducing the bunch length could become important. The choice of harmonic number for the resonant rf systems might be different for any of these reasons, but it is almost surely necessary to have more segments per batch if the batch emittance is larger. Should the option of taking two Booster cycles to perform the rotations be chosen, the extra time available would allow debunching the 53 MHz structure in the batch using the broadband rf system. A reduction in the energy spread, eqivalently in ε_ℓ, of ~ 20 % can be expected. A pragmatic adaptation is suggested by the bunch current profiles in Figs. 2 and 3. If the activation limits are somewhat tolerant, the four σ width of the four successive bunches can be taken for the time spread of the injected muon bunches. The losses from the long tails of the proton distribution may be acceptable. For example, the four-σ width of the first pulse is 34 ns and of the fourth pulse is 58 ns, considerably shorter than the quoted full bunch width of 111 ns.

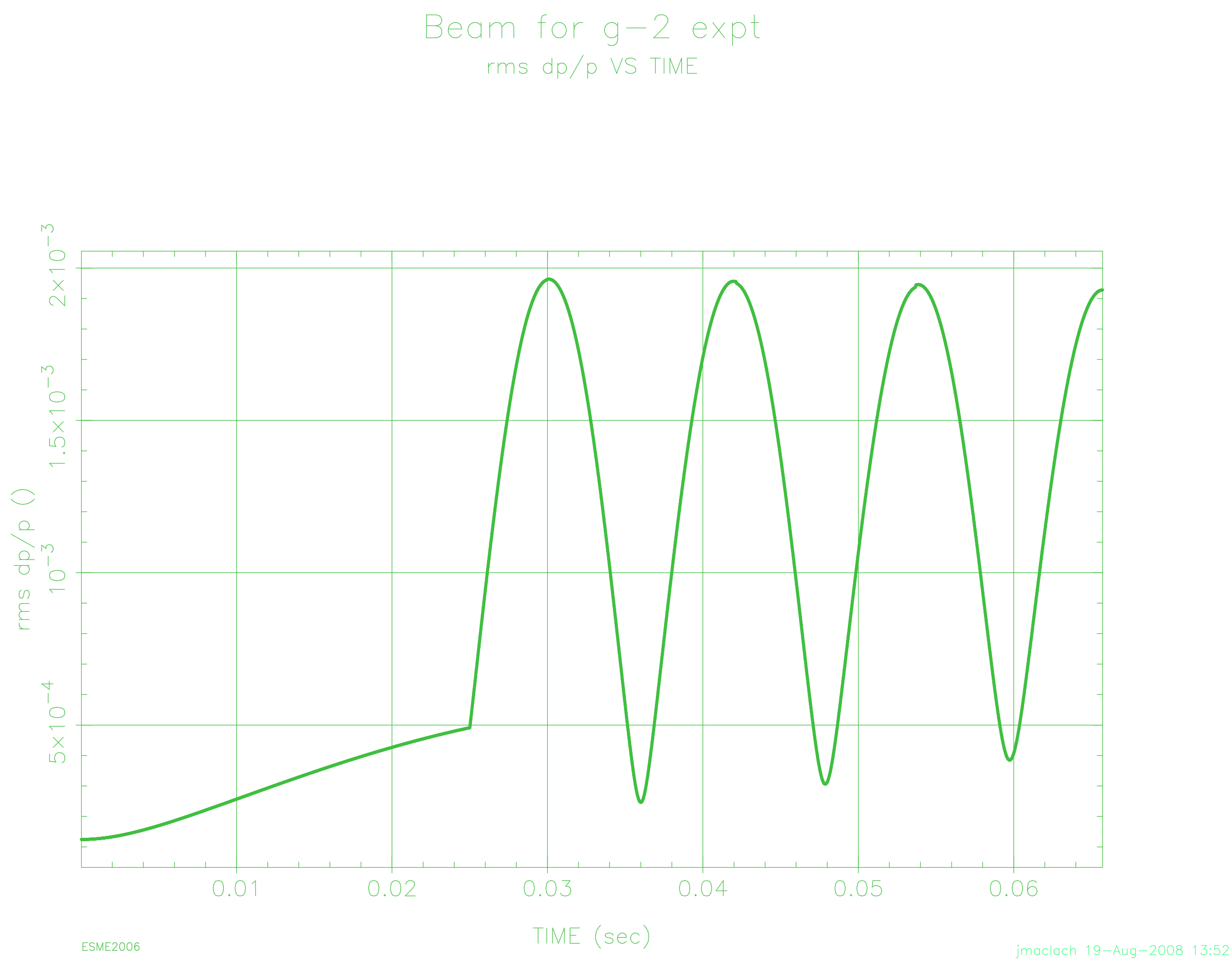

Figure 1: RMS $\frac{\Delta p}{p}$ in the Recycler vs. time [s]

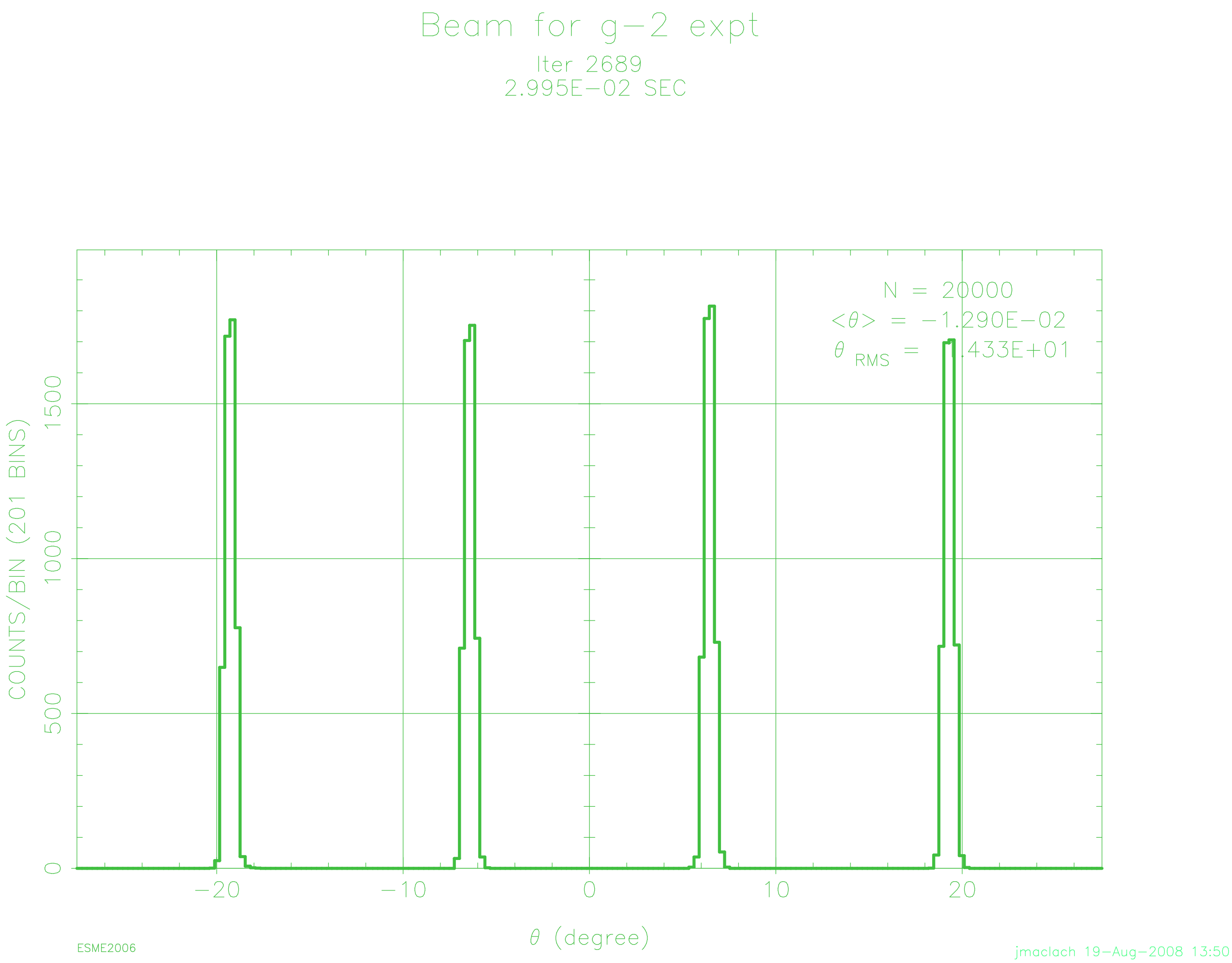

Figure 2: Bunch current (arbitray units) vs. azimuth in the Recycler for all four bunches just before first extraction. The original Booster batch of $\sim 1.6\mu$s extends from $-25.714°$ to $25.714°$.

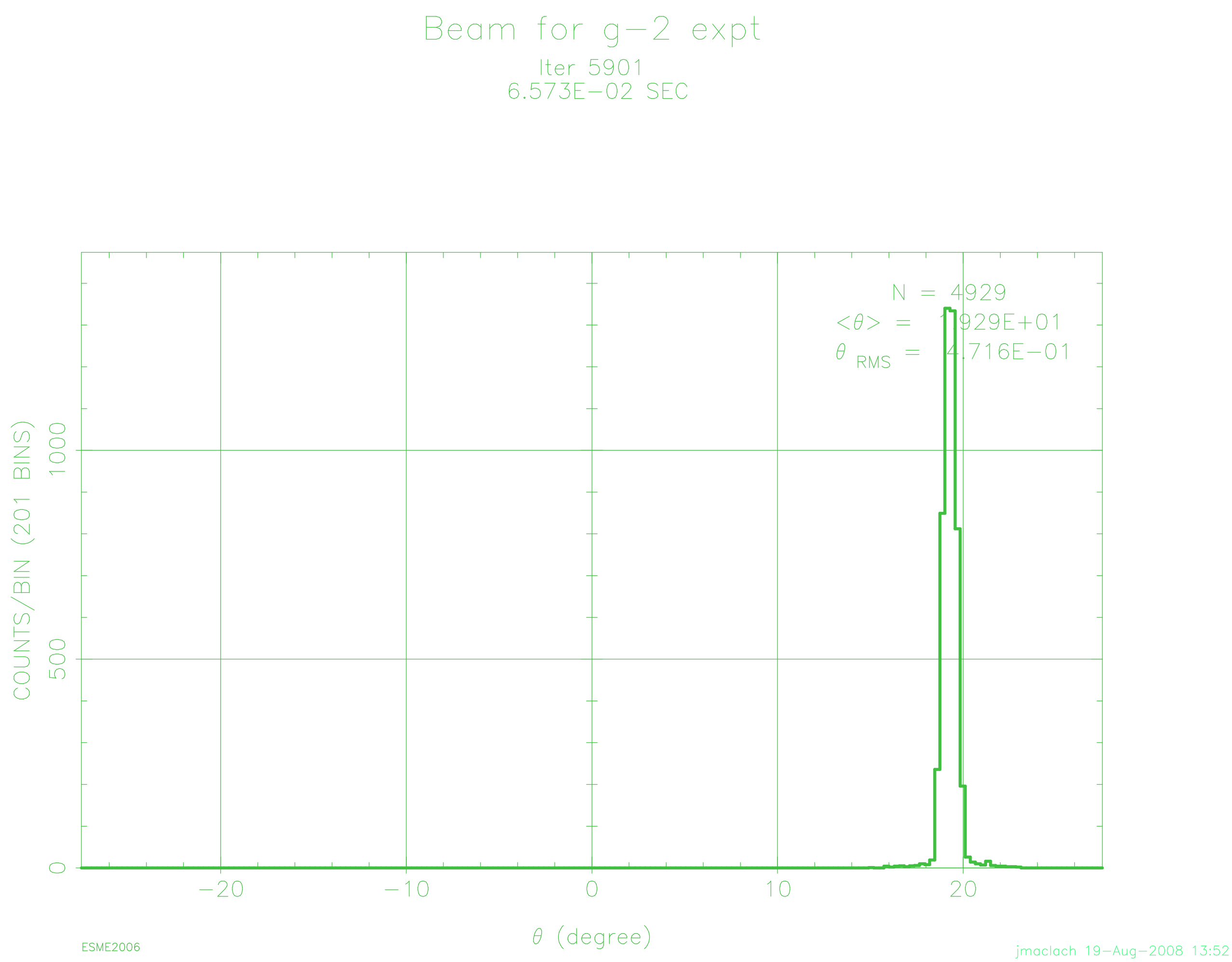

Figure 3: Bunch current (arbitrary units) vs. azimuth for the last bunch just before extraction

Table 3: Approximate Booster & Recycler longitudinal phase space parameters for order of magnitude estimates

Best case	Value	Units
Booster batch ε_ℓ	5	eVs
Recycler energy aperature	1.4	%
Emittance dilution factor	1	
Worst case	**Value**	**Units**
Booster batch ε_ℓ	8	eVs
Recycler energy aperature	1	%
Emittance dilution factor	2	

5 Arithmetic

Order of magnitude estimates are sufficient to illustrate the theorem that there is no free lunch. The Booster batches are divided into a few segments which are manipulated to produce short bunches. The longitudinal emittance ε_ℓ of a batch is a few eVs, say 5 – 8. That number, whatever it is exactly, and the momentum aperture of the Recycler constrain the possible bunch width because ε_ℓ is at best conserved. Practically, there is at least some emittance dilution resulting from the beam gymnastics, plausibly a factor of two. Taking worst case numbers in a rough estimate, one finds a bunch width of 200 ns; using only optimistic numbers, one could perhaps get as narrow as 50 ns.

6 Summary

This note demonstrates a technically adequate approach to the desired bunching of Booster batches for muon production with subsequent injection into the BNL/BU g-2 ring. Some of the possibilities for further development are mentioned, but none of the leads have been pursued for this note. At the time of writing, perhaps the most attractive option is to allow two Booster cycles for one g-2 cycle of four injections. This idea promises lower rf voltage requirements, longer time between g-2 fills, and interleaved beam sharing capability. Eventually we would want to do a multivariate optimization for cost and beam quality.

Acknowledgement

We gratefully acknowledge the assistance from informed and spirited discussion with and among M. Popovic, C. Ankenbrandt, J-F Ostiguy, M. Syphers, and D. Neuffer.

References

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[3] J. MacLachlan, “Particle Tracking in E-ϕ Space for Synchrotron Design & Diagnosis”, Fermilab-CONF-92/333 (Nov. 92), presented at $12^{\underline{th}}$ Int’l Conf. on Appl. of Acc. in Res. and Ind., Denton TX, 4 Nov. 1992